Nitrate Leaching Flux in Bare Soils with Effective Drainage

Stephen Labuz, Undergraduate[1]; John Nieber, Professor[1,2]; Chris Lenhart, Assistant Professor[1,2]; Brad Hanson, Senior Scientist[1,2]
[1]University of Minnesota, [2]Department of Bioproducts and Biosystems Engineering

Introduction

Nitrogen in essential for growth and reproduction of all life forms. Nitrate however, in excessive amounts, can degrade ecosystems and pollute drinking water. Even without fertilizer inputs, Midwestern soils can mineralize with the presence of organic matter, produce nitrate, and transport that nitrate into other water bodies where the nutrient may be limiting.

Bare soils in agricultural fields and stormwater best management practices such as rain gardens, are examples of low nitrogen inputs, effective drainage, and high nitrate output. Rain gardens with and without drains can be responsible for filtering large volumes of water and use a variety of plants to treat stormwater. Below the rooted zone is where nitrate is being leached in rain gardens and throughout the soil column in bare farm fields.

Because of the damage flooding causes, effective drainage is important to prevent flash floods. Although, nitrate is mobile in soil water and detention time from the surface to the drain may not be long enough for nitrate to be removed in many cases.

Most nitrate leaching research has studied nitrate losses on an agricultural field at the seasonal scale to manage for fertilizer application. This research quantifies nitrate leaching from individual storm events with little nitrogen input to the system. Not only is learning what season leaching is likely to occur important, but also when will the most potent nitrate concentrations occur during drainage.

Methods and Materials

Three tanks (A, B, and C) were constructed in a laboratory setting and fitted with a drain pipe. All three tanks had 2 cm of course sand at the bottom and 30 cm of sandy loam soil overlying the sand (soil is native to southern Minnesota). The contents of the drain pipe are as follows..

- Tank A – 90% sand and 10% iron filings
- Tank B – 90% sand and 10% grass seed
- Tank C – 100% air space

The water inputs were based off rain achieves of 2012 from the Twin Cities, Minnesota and using the SCS curve number method (Equation 1) inputs were generated. The 5 most intensive storms were simulated for this project.

$$S = \frac{1000}{CN\ (group\ C)} - 10; \quad Q = \frac{(ppt - 0.2S)^2}{(ppt + 0.8S)}$$

Equation 1 – SCS curve number method which depends on the rain storm depth and ground cover type.

During event simulated event, water samples were collected and tested for nitrate concentration using a nitrate probe (Hach NITRATAX). The overall mass of nitrate exiting the tank was calculated by equation 2.

$$\sum_{i=2}^{6} Q_N\left(\frac{L}{\text{sec}}\right) x\ [NO_3]_N\left(\frac{mg}{L}\right)\ x\ (T_N - T_{N-1})(\text{sec}) = \frac{Total\ Mass\ Nitrate\ Leached}{Tank}$$

Equation 2 – Total mass of nitrate exiting the tank is a function of flow, measured nitrate concentration, and difference in time of water sample collected as seen in Figure 8.

Results

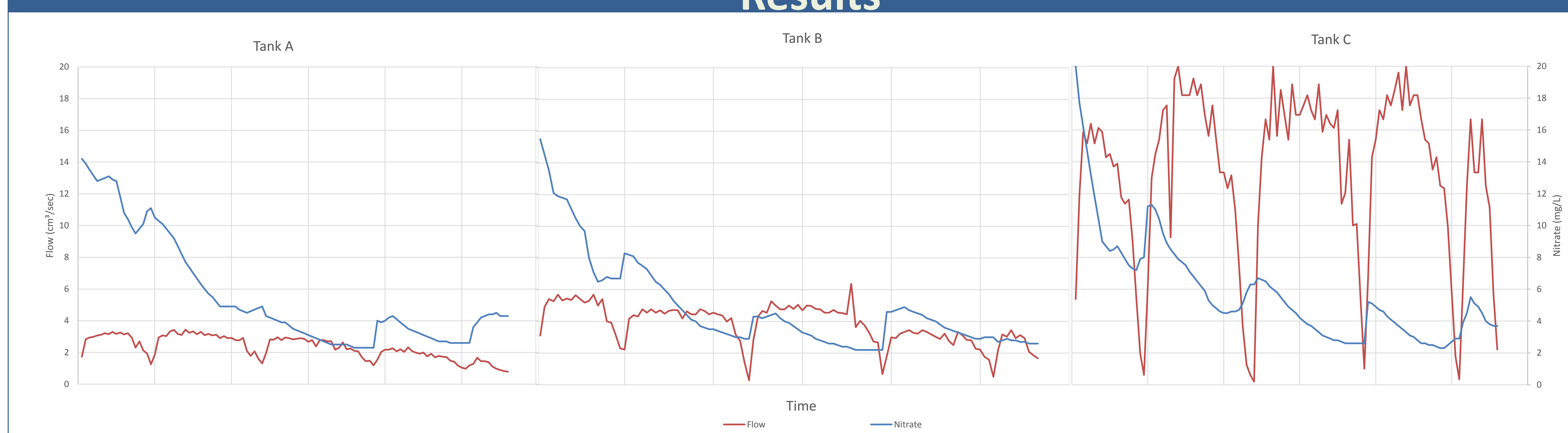

Figure 5 – Tank A output nitrate and flow **Figure 6** – Tank B output nitrate and flow **Figure 7** – Tank C output nitrate and flow

Figures 5, 6, 7, and 8 illustrate nitrate leaching through experimental tanks layered with sand and overlying bare soil. There were five separate simulated storm event.

Figure 1 - Setup of each tank

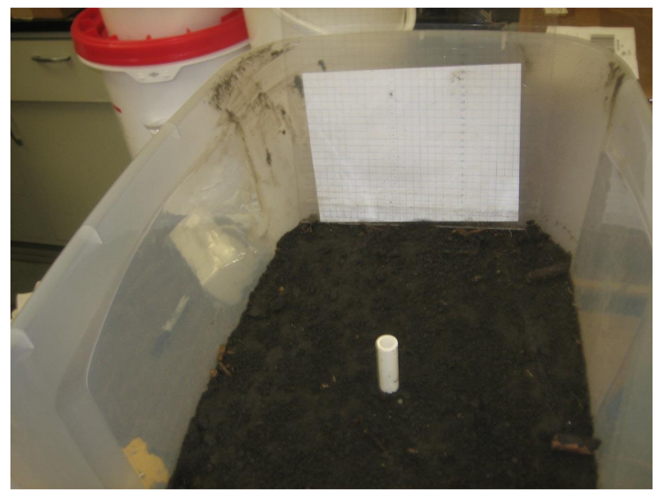

Figure 2 - Looking into a tank with overflow pipe.

Figure 3 – Stuffed drain pipe of Tank A

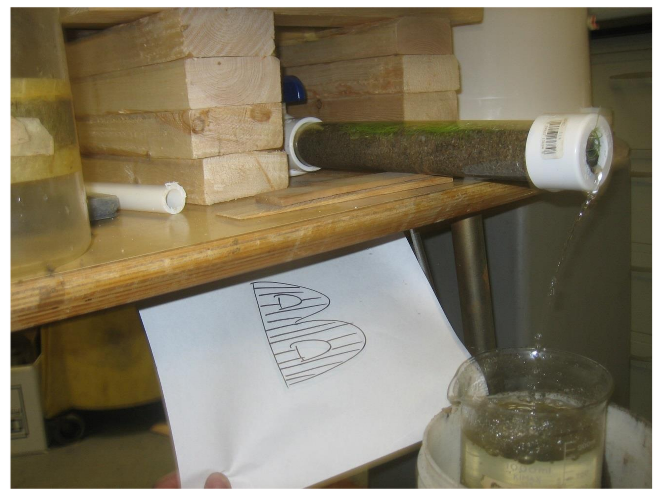

Figure 4 – Water flowing through Tank B's pipe

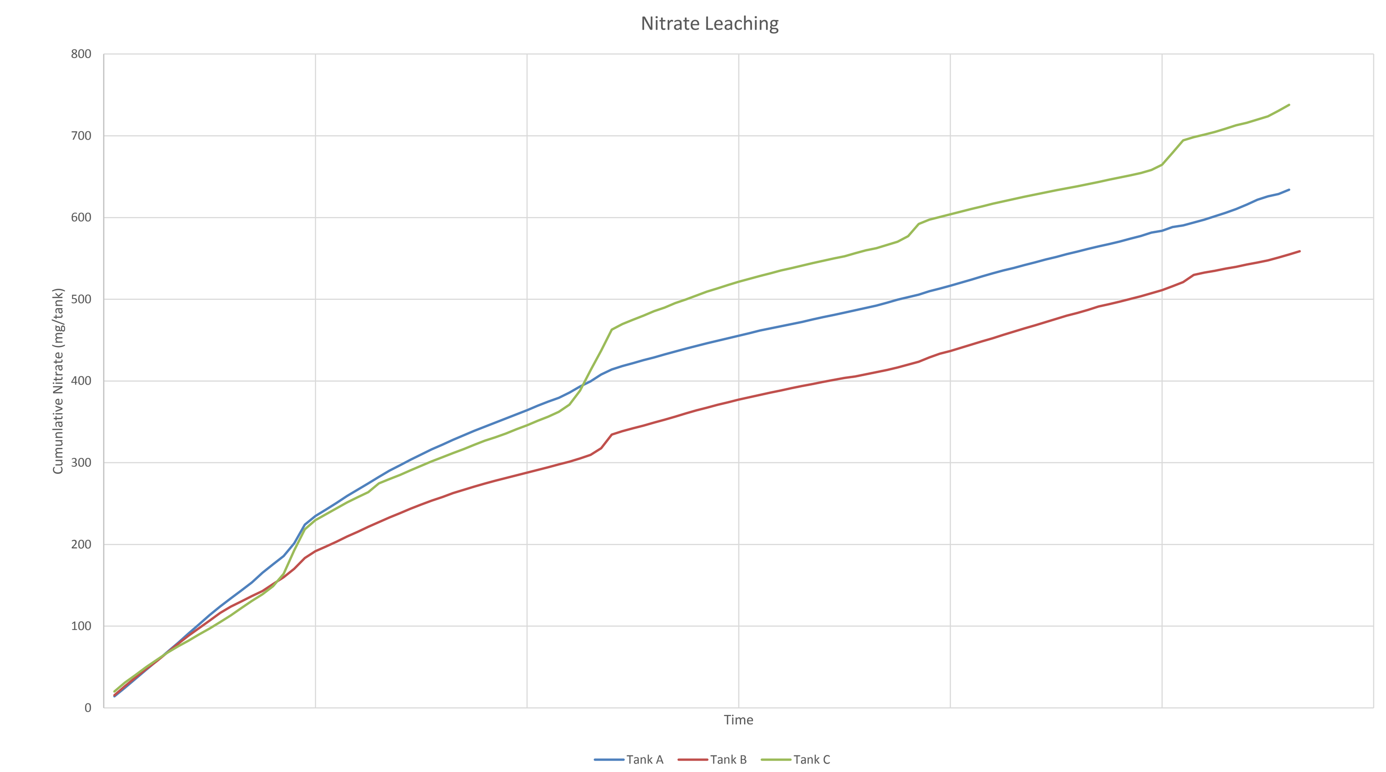

Figure 8 – Cumulative nitrate release described by each tank.

Discussion

All three tanks displayed a similar pattern of high and low concentrations, which was a function of flow strength. During the end of the event, nitrate concentrations were lowest. The startup period of an event had high nitrate concentrations. For example, Tank C (Figure 7) was unstuffed and had the strongest flow, and highest cumulative nitrate output (Figure 8). The tanks with stuffed drain pipes still released nitrate but was less dramatic, along with their flow rates. The most potent nitrate concentrations were experienced at the beginning of an event when water not released from the previous event was pushed through with the addition of a new slug. The stuffed pipes drained more slowly but still effectively drained and released less nitrate.

During the startup period of the fifth event, Tank B (sand enhanced with grass seed) did not experience a spike of nitrate but was completely drained at the end. This result resembles a possible solution to potent nitrate leaching.

Figure 8 shows the cumulative weight of nitrate exported from the system which steadily increases over time. The carbon to nitrogen ratio was evidently low and additional carbon needed to be present to sorb, not release nitrate. Tank B released the least and its drain pipe was enhanced with grass seed (carbon).

Conclusions

Stuffing drain pipes can have several advantages in rural and urban settings including, nitrate reduction, decrease in peak flow out of the system, immobilization of larger particles and debris, and preventing carp from traveling to other habitats connected by drain pipes.

Physical mechanisms, like plant roots should be present wherever mineral soils are to uptake nitrate. Bare agricultural soils should have a cover crop to prevent nitrate from leaching and unrooted zones beneath stormwater best management practices should be free of organic matter, like sand.

Contact

Stephen Labuz
University of Minnesota
Email: labuz011@umn.edu
Phone: (651)808-8829

References

1. Addiscott, T. M. (1977). A simple computer model for leaching in structured soils. *Journal of soil Science*, *28*(4), 554-563.
2. Babcock, L. (2011). The Effect of Filtering Water through Charcoal and Sand on Nitrogen Content.
3. Dietz, M. E., & Clausen, J. C. (2005). A field evaluation of rain garden flow and pollutant treatment. *Water, Air, and Soil Pollution*, *167*(1-4), 123-138.
4. Erickson, A. J., Gulliver, J. S., & Weiss, P. T. (2007). Enhanced sand filtration for storm water phosphorus removal. *Journal of Environmental Engineering*,*133*(5), 485-497.
5. Good, J. F., O'Sullivan, A. D., Wicke, D., & Cochrane, T. A. (2012). Contaminant removal and hydraulic conductivity of laboratory rain garden systems for stormwater treatment. *Water Science & Technology*, *65*(12).
6. Henderson, C., Greenway, M., & Phillips, I. (2007). Removal of dissolved nitrogen, phosphorus and carbon from stormwater by biofiltration mesocosms.*Water Science & Technology*, *55*(4), 183-191.
7. Lewis Jr, W. M., Wurtsbaugh, W. A., & Paerl, H. W. (2011). Rationale for control of anthropogenic nitrogen and phosphorus to reduce eutrophication of inland waters. *Environmental science & technology*, *45*(24), 10300-10305.
8. Moreno, F., Cayuela, J. A., Fernández, J. E., Fernández-Boy, E., Murillo, J. M., & Cabrera, F. (1996). Water balance and nitrate leaching in an irrigated maize crop in SW Spain. *Agricultural water management*, *32*(1), 71-83.
9. Morgan, J. (2010). WHEN DO WE NEED TO REPLACE BIORETENTION MEDIA?
10. Palhegyi, G. E. (2009). Modeling and sizing bioretention using flow duration control. *Journal of Hydrologic Engineering*, *15*(6), 417-425.